Multi-Agent Software Design and Engineering for Human Centered Collaborative Autonomous Space Systems
NASA Intelligent Systems NCC2-1283 Final Report

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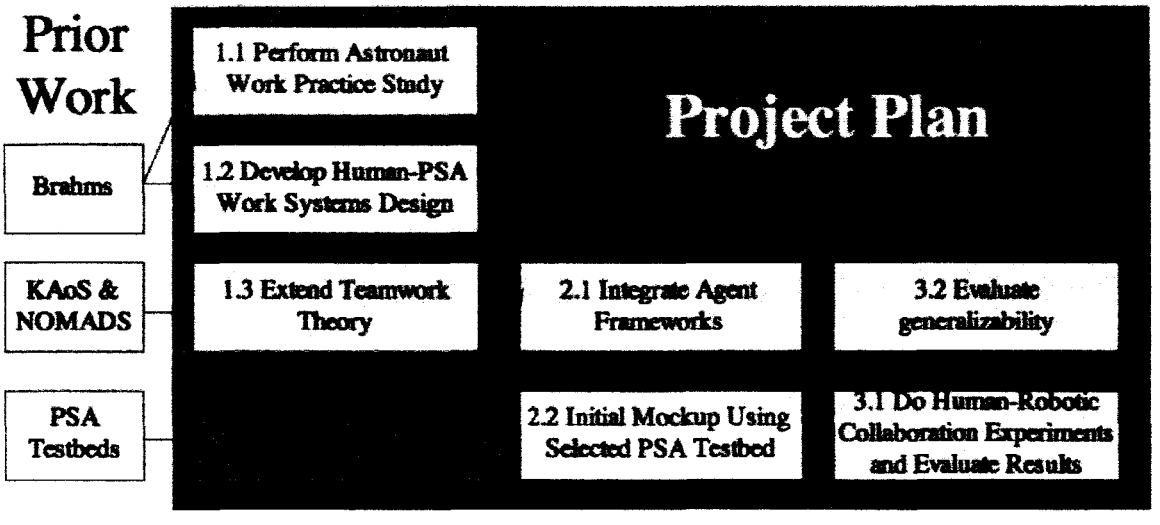
Detailed results of this three-year project are available in 37 publications, including 7 book chapters, 3 journal articles, and 27 refereed conference proceedings. In addition, various aspects of the project were the subject of 31 invited presentations and 6 tutorials at international conferences and workshops. Good descriptions of prior and ongoing work on foundational technologies in Brahms, KAoS, NOMADS, and the PSA project can be found in numerous publications not listed here.



For those who would like to explore the results in more detail, we enumerate some of the references that provide useful summaries of key phases of the project plan:

1.1. Perform Astronaut Work Practice Study. A good summary of the results of the astronaut work practice study and the resultant Brahms model can be found in 15.
1.2. Develop human-PSA work systems design. References 2/3 and 16 outline some initial observations and lessons learned respecting the design of human-automation work systems in general, with application to PSA.
1.3. Extend Teamwork theory. Reference 4 is an exploration of aspects of agent systems that make them acceptable to people, with categorizations of examples of relevant KAoS policies. Reference 5 presents an analysis of the dimensions of adjustable autonomy and how they relate to principles of mixed-initiative interaction. Reference 32 looks at these same issues from the perspective of system trustworthiness, and contrasts the KAoS approach to adjustable autonomy with related research by others, Reference 6 discusses coordination analogues in animal and human cultures to the problems of human-agent interaction.
2.1, Integrate agent frameworks. Reference 18 provides a summary of Brahms and KAoS

integration.

2.2. Initial mockup using selected PSA testbed. Reference 11a provides a description of the PSA platform and reference 13 discusses our initial evaluation of the PSA as a testbed platform.

3.1. Do human-robotic collaboration experiments and evaluate results. Due to lack of timely availability of the PSA as a testbed platform, we adopted the annual field experiments at the Mars Desert Research Station for the Mobile Agents project as our testbed platform. Reference 18 includes an overview one of the annual field tests.

3.2. Evaluate generalizability. References 7 and 10 further develop a theory of coordination and common ground in joint human-automation activity. We believe that this theoretical generalization of our work on the project can be applied widely to all future NASA missions involving people and automation. These references also discuss ten challenges for future research and development.

Book Chapters

1, Bradshaw, J.M., Suri, N., Breedy, M., Cañas, A., Davis, R., Ford, K., Hoffman, R., Jeffers, R., Kulkarni, S., Lott, J., Reichherzer, T., and Uszok, A. (2002). Terraforming Cyberspace. In D. Marinescu and C. Lee (Eds.), *Process Coordination and Ubiquitous Computing*. Boca Raton, FL: CRC Press, 165-185.

2. Bradshaw, J. M., Sierhuis, M., Acquisti, A., Feltovich, P., Hoffman, R., Jeffers, R., Prescott, D., Suri, N., Uszok, A., & Van Hoof, R. (2003). Adjustable autonomy and human-agent teamwork in practice: An interim report on space applications. In H. Hexmoor, R. Falcone, & C. Castelfranchi (Ed.), *Agent Autonomy*. Dordrecht, The Netherlands: Kluwer, pp. 243-280.

3. Bradshaw, J. M., Sierhuis, M., Acquisti, A., Feltovich, P., Hoffman, R., Jeffers, R., Prescott, D., Suri, N., Uszok, A., & Van Hoof, R. (2003). Adjustable autonomy and human-agent teamwork in practice: An interim report on space applications. The Role of Humans in Intelligent and Automated Systems. Publication reference RTO-MP-088 (ISBN: 92-837-0031-7). NATO Research and Technology Organization Report, pp. KN6 1-30.

4. Bradshaw, J. M., Beautement, P., Breedy, M., Bunch, L., Drakunov, S. V., Feltovich, P. J., Hoffman, R. R., Jeffers, R., Johnson, M., Kulkarni, S., Lott, J., Raj, A., Suri, N., & Uszok, A. (2004). Making agents acceptable to people. In N. Zhong and J. Liu (Eds.), *Intelligent Technologies for Information Analysis: Advances in Agents, Data Mining, and Statistical Learning*, Berlin: Springer Verlag, pp, 361-400.

5. Bradshaw, J.M., Jung, H., Kulkarni, S., & Taysom, W. (2004). Dimensions of adjustable autonomy and mixed-initiative interaction. In M. Nickles, M. Rovatsos & G. Weiss (Eds.), *Agents and Computational Autonomy: Potential, Risks, and Solutions*. Lecture Notes in Computer Science, Vol. 2969. Berlin: Springer-Verlag, pp. 17-39.

6. Feltovich, P. J., Bradshaw, J. M., Jeffers, R., Suri, N., & Uszok, A. (2004). Social order and adaptability in animal and human cultures as analogues for agent communities: Toward a policy-based approach. In A. Omicini, P. Petta, & J. Pitt (Eds.) *Engineering Societies in the Agents World IV*. Lecture Notes in Computer Science Series. Berlin, Germany: Springer-Verlag, pp. 21-48.

7. Klein, G., Feltovich, P. J., Bradshaw, J. M., & Woods, D. D. (2004). Common ground and coordination in joint activity. In W. B. Rouse & K. R. Boff (Eds.), *Organizational Simulation*. New York City, NY: John Wiley, in press.

Journal Articles

8. Bradshaw, J.M., Suri, N., Canas, A.J., Davis, R., Ford, K.M., Hoffman, R., Jeffers, R., and Reichherzer, T. (2001) Terraforming Cyberspace. *IEEE Computer*, July, 48-56.

9. Hoffman, R. R., Bradshaw, J. M., Hayes, P. J. & Ford, K. M. (2003). The Borg hypothesis. *IEEE Intelligent Systems,* September/October, pp. 73-75.

10. Klein, G., Woods, D. D., Bradshaw, J. M., Hoffman, R. R., & Feltovich, P. J. (2004). Ten challenges for making automation a "team player" in joint human-agent activity. *IEEE Intelligent Systems,* in press.

Refereed Conference Proceedings

11a. Gawdiak, Y., Bradshaw, J.M., Williams, B.R. & Thomas, H. (2000). R2D2 in a softball: The Personal Satellite Assistant. *Proceedings of the ACM Conference on Intelligent User Interfaces*, New Orleans, LA, January 9-12, New York: ACM, pp. 125-128.

11b. Bradshaw, Jeffrey M. (2001). Terraforming cyberspace, Invited talk in the *Proceedings of the First IEEE/ACM Symposium on Cluster Computing and the Grid (CCGrid'2001) Workshop*, Brisbane, Australia, 15-18 May. Los Alamitos, CA: IEEE Computer Society, 19-20.

12. Bradshaw, J.M., Suri, N., Kahn, M. Sage, P., Weishar, D., and Jeffers, R. (2001). Terraforming cyberspace: Toward a policy-based grid infrastructure for secure, scalable, and robust execution of Java-based multi-agent systems. *Proceedings of the Second International Workshop on Infrastructure for Agents, Mobile Agent Systems, and Scalable Mobile Agents Systems at the Fifth International Conference on Autonomous Agents (Agents-2001),* Montreal, Canada, 29 May,

13. Bradshaw, J.M., Sierhuis, M., Gawdiak, Y., Jeffers, R., Suri, N., Greaves, M. Teamwork and adjustable autonomy for the Personal Satellite Assistant. *Proceedings of the Workshop on Autonomy, Delegation, and Control: Interacting*

with Autonomous Agents at the Seventeenth International Joint Conference on Artificial Intelligence (IJCAI-2001), Seattle, WA, 6 August, pp. ??.

14. Bradshaw, J. M. (2001). Terraforming cyberspace. Proceedings of the 2nd International Workshop of Central and Eastern Europe on Multi-Agent Systems (CEEMAS 2001), Krakow, Poland, 26-29 September, pp. ??.

15. Acquisti, A., Sierhuis, M., Clancey, W. J., & Bradshaw, J. M. (2002). Agent-based modeling of collaboration and work practices onboard the International Space Station. *Proceedings of the Eleventh Conference on Computer Generated Forces and Behavior Representation*, Orlando Florida, 7-9 May, pp. ??.

16. Bradshaw, J. M., Sierhuis, M., Feltovich, P., Acquisti, A., Jeffers, R., Prescott, D., Suri, N., Uszok, A., and Van Hoof, R. (2002). What we can learn from human-agent teamwork from practice. *Proceedings of the Workshop on Teamwork and Coalition Formation, Conference on Autonomous Agents and Multi-Agent Systems (AAMAS 2002),* Bologna, Italy, 15 July, pp. ??.

17. Bradshaw, J. M., Sierhuis, M., Acquisti, A., Feltovich, P., Hoffman, R. R., Jeffers, R., Suri, N., Uszok, A., & Van Hoof, R. (2003) Living with agents and liking it: Addressing the technical and social acceptability of agent technology. *Proceedings of the AAAI Stanford Spring Symposium on Human Interaction with Autonomous Systems in Complex Environments.* Stanford University, 24-26 March, Menlo Park, CA: AAAI Press.

18. Sierhuis, M., Bradshaw, J. M., Acquisti, A., Van Hoof, R., Jeffers, R., & Uszok, A. (2003). Human-agent teamwork and adjustable autonomy in practice. *Proceedings of the Seventh International Symposium on Artificial Intelligence, Robotics and Automation in Space (i-SAIRAS).* 19-23 May, Nara, Japan.

19. Suri, N., Carvalho, M., Bradshaw, J. M., Breedy, M. R., Cowin, T. B., Groth, P. T., Saavendra, R., & Uszok, A. (2003). Enforcement of communication policies in software agent systems through mobile code. *Proceedings of the IEEE Fourth International Workshop on Policy (Policy 2003).* Lake Como, Italy, 4-6 June, Los Alamitos, CA: IEEE Computer Society, pp. 247-250.

20. Uszok, A., Bradshaw, J. M., Jeffers, R., Suri, N., Hayes, P., Breedy, M. R., Bunch, L., Johnson, M., Kulkarni, S., & Lott, J. (2003). KAoS policy and domain services: Toward a description-logic approach to policy representation, deconfliction, and enforcement. *Proceedings of the IEEE Fourth International Workshop on Policy (Policy 2003).* Lake Como, Italy, 4-6 June, Los Alamitos, CA: IEEE Computer Society, pp. 93-98.

21. Bradshaw, Jeffrey M. (2003). Making agents acceptable to people. In V. Marik, J. Müller, & M. Pechoucek (Eds.), *Multi-Agent Systems and Applications III: Proceedings of the Third International Central and Eastern European Conference*

on Multi-Agent Systems (CEEMAS 2003), Prague, Czech Republic, June 16-18. LNAI 2691. Berlin, Germany: Springer, pp. 1-3.

22. Uszok, A., Bradshaw, J. M., & Jeffers, R. (2004). KAoS: A policy and domain services framework for grid computing and grid computing and semantic web services. In C. Jensen, S. Poslad, & T. Dimitrakos (Eds.), *Trust Management: Second International Conference (iTrust 2004) Proceedings.* Oxford, UK, March/April, Lecture Notes in Computer Science 2995, Berlin: Springer, pp. 16-26.

23. Bradshaw, J. M., Uszok, A., Jeffers, R., Suri, N., Hayes, P., Burstein, M. H., Acquisti, A., Benyo, B., Breedy, M. R., Carvalho, M., Diller, D., Johnson, M., Kulkarni, S., Lott, J., Sierhuis, M., & Van Hoof, R. (2003). Representation and reasoning for DAML-based policy and domain services in KAoS and Nomads. *Proceedings of the Autonomous Agents and Multi-Agent Systems Conference (AAMAS 2003).* 14-18 July, Melbourne, Australia. New York, NY: ACM Press, pp. 835-842.

24. Suri, N., Bradshaw, J. M., Burstein, M. H., Uszok, A., Benyo, B., Breedy, M. R., Carvalho, M., Diller, D., Groth, P. T., Jeffers, R., Johnson, M., Kulkarni, S., & Lott, J. (2003). DAML-based policy enforcement for semantic data transformation and filtering in multi-agent systems. *Proceedings of the Autonomous Agents and Multi-Agent Systems Conference (AAMAS 2003).* 14-18 July, Melbourne, Australia. New York, NY: ACM Press, pp. 1132-1133.

25. Feltovich, P., Bradshaw, J. M., Jeffers, R., & Uszok, A. (2003). Order and KAoS: Using policy to represent agent cultures. *Proceedings of the AAMAS 03 Workshop on Humans and Multi-Agent Systems.* July, Melbourne, Australia.

26. Johnson, M., Chang, P., Jeffers, R., Bradshaw, J. M., Soo, V.-W., Breedy, M. R., Bunch, L., Kulkarni, S., Lott, J., Suri, N., & Uszok, A. (2003). KAoS semantic policy and domain services: An application of DAML to Web services-based grid architectures. *Proceedings of the AAMAS 03 Workshop on Web Services and Agent-Based Engineering.* July, Melbourne, Australia.

27. Tonti, G., Bradshaw, J. M., Jeffers, R., Montanari, R., Suri, N., & Uszok, A. (2003). Semantic Web languages for policy representation and reasoning: A comparison of KAoS, Rei, and Ponder. *Proceedings of the International Semantic Web Conference (ISWC 03).* Sanibel Island, Florida, October.

28. Uszok, A., Bradshaw, J. M., Hayes, P., Jeffers, R., Johnson, M., Kulkarni, S., Breedy, M. R., Lott, J., & Bunch, L. (2003). DAML reality check: A case study of KAoS domain and policy services. Internal technical report. Short version of this paper appears in *Proceedings of the International Semantic Web Conference (ISWC 03).* Sanibel Island, Florida, October.

29. Feltovich, P. J., Bradshaw, J. M., Jeffers, R. & Uszok, A. (2003) Social order and

adaptability in animal, human, and agent communities. *Proceedings of the Fourth International Workshop on Engineering Societies in the Agents World*, Imperial College, London, 29-31 October.

30. Bradshaw, J. M., Acquisti, A., Allen, J., Breedy, M., Bunch, L., Chambers, N., Galescu, L, Goodrich, M., Jeffers, R., Johnson, M., Jung, H., Lott, J., Olsen, D., Sierhuis, M., Suri, N., Tonti, G., van Hoof, R., & Uszok, A. (2004). Teamwork-centered autonomy for extended human-agent interaction in space applications. *Proceedings of the AAAI Spring Symposium,* Stanford, CA: AAAI Press, March 22-24.

31. Jung, H., Bradshaw, J. M., Kulkarni, S., Breedy, M., Bunch, L, Feltovich, P., Jeffers, R., Johnson, M., Lott, J., Suri, N., Taysom, W., Tonti, G., & Uszok, A. (2004). An ontology-based representation for policy-governed adjustable autonomy. *Proceedings of the AAAI Spring Symposium,* Stanford, CA: AAAI Press, March 22-24.

32. Bradshaw, J. M., Jung, H., Kulkarni, S., Allen, J. Bunch, L., Chambers, N., Feltovich, P., Galescu, L., Jeffers, R., Johnson, M., Taysom, W. & Uszok, A. (2004). Toward trustworthy adjustable autonomy and mixed-initiative interaction in KAoS. *Proceedings of the AAMAS 2004 Trust workshop*, New York City, NY, July 19-23, pp. 9-20.

33. Lott, J., Bradshaw, J. M., Uszok, A., & Jeffers, R. (2004). Using KAoS policy and domain services within Cougaar. *Proceedings of the Open Cougaar Conference 2004.* New York City, NY, 20 July, pp. 89-95.

34. Tonti, G., Montanari, R., Bradshaw, J. M., Bunch, L., Jeffers, R., Suri, N. & Uszok, A. (2004) Automated generation of enforcement mechanisms for semantically-rich policies in Java-based multi-agent systems. *Proceedings of the First IEEE Symposium on Multi-Agent Security and Survivability (MAS&S 2004).* Philadelphia, PA: Drexel University, 30-31 August, in press.

35. Bradshaw, J. M., Feltovich, P. J., Jung, H., Kulkarni, S., Allen, J., Bunch, L. Chambers, N. Galescu, L. Jeffers, R., Johnson, M. Sierhuis, M., Taysom, W., Uszok, A. & Van Hoof, R. (2004). Policy-based coordination in joint human-agent activity. Invited talk and paper. *Proceedings of the IEEE International Conference on Systems, Man, and Cybernetics,* The Hague, The Netherlands, 10-13 October.

36. Marik, V., Bradshaw, J. M., Hall, K., Luck, M. & Shehory, O. (2004). Panel Session: Coordination of Collaborative Intelligent Systems. *Proceedings of the IEEE International Conference on Systems, Man, and Cybernetics,* The Hague, The Netherlands, 10-13 October.

37. Uszok, A & Bradshaw, J. M. (2004). Applications of KAoS policy and domain services to coalition operations, survivable logistics support, and human-robotic teamwork. Proceedings of the International Workshop on Monitoring, Security, and Rescue Techniques in Multiagent Systems (MSRAS 2004), Płock, Poland, 7-9 June. Also to be published in the volume *Advances in Soft Computing*, Springer-Verlag, 2004 and a special issue of *Fundamenta Informaticae,* 2005.

Invited Presentations

38. Bradshaw, J. M., Acquisti, A., Jeffers, R., Sierhuis, M., and Suri, N. (2001). Agent framework support for human-robotic teamwork in practice. Invited presentation at the *NASA Intelligent Systems Human-Centered Computing Workshop*, Moffett Field, CA: NASA Ames Research Center, 18-19 September.

39. Bradshaw, J. M. (2001). Terraforming cyberspace. Invited colloquium, EPFL, Zurich, Switzerland, 15 November.

40. Bradshaw, J. M. and Suri, N. (2001). Terraforming cyberspace. Presentation at the *Workshop on Process Coordination and Ubiquitous Computing*. Orlando: University of Central Florida, 14 December.

41. Bradshaw, J. M., Acquisti, A., Hayes, P., Jeffers, R., Prescott, D., Sierhuis, M., Suri, N., Uszok, A., and Van Hoof, R. (2002). Design for collaboration in human-robotic teams in practice. Invited presentation at the *NASA Intelligent Systems Human-Centered Computing Workshop*, Pensacola, FL, 26 February.

42. Bradshaw, J. M. (2002). Living with agents: From human-agent teamwork to cognitive prostheses. Invited colloquium, Air Force Research Laboratory, Wright-Patterson AFB, Dayton, OH, 19 March.

43. Bradshaw, J. M. (2002). Living with agents: From human-agent teamwork to cognitive prostheses. Invited plenary talk, *Fifteenth International Florida Artificial Intelligence Research Society Conference (FLAIRS 2002)*, Pensacola, FL, 14-16 May.

44. Bradshaw, J. M. (2002). Living with agents: From human-agent teamwork to cognitive prostheses. Invited keynote presentation, *International Conference on Intelligent Tutoring Systems*, Biarritz France, 5 June.

45. Bradshaw, J. M. (2002). Living with agents: From human-agent teamwork to cognitive prostheses. Invited Keynote Address, North Atlantic Treaty Organization (NATO) Research and Technology Agency Human Factors and Medicine Panel Symposium on The Role of Humans in Intelligent and Automated Systems. Warsaw, Poland, 7-9 October.

46. Bradshaw, J. M. (2002). Lessons learned in the development and application of

DAML-based representation and reasoning methods for agent domains and policies. Invited workshop presentation for international FIPA meeting, Pensacola, FL, 15 October.

47. Bradshaw, J. M. (2002). Living with agents: From human-agent teamwork to cognitive prostheses. Invited colloquium. Southampton, England, University of Southampton Department of Computer Science, 12 November.

48. Bradshaw, J. M. (2002). Living with agents: From human-agent teamwork to cognitive prostheses. Invited colloquium. London, England, Imperial College, 13 November.

49. Bradshaw, J. M. (2002). Invited presentation at the 2002 National Conference and 49th Annual Meeting of the American Astronautical Society, Santa Clara, CA, 19-21 November.

50. Bradshaw, J. M. (2002). A glimpse at the future of agent technology. Invited presentation and broadcast as part of the Technology Series, MITRE Corporation, Boston, MA, 4 December.

51. Bradshaw, J. M. (2003). Software Agent Technology. Invited presentation to the US State Department, Washington, D.C., 5 January.

52. Bradshaw, J. M. (2003). Living with agents: From human-agent teamwork to cognitive prostheses. Invited colloquium at Brigham Young University, Provo, Utah, 13 January.

53. Bradshaw, J. M. (2003). Living with agents: From human-agent teamwork to cognitive prostheses. Invited colloquium at University of South Florida, Tampa, Florida, 15 January.

54. Bradshaw, J. M. (2003). Adjustable autonomy and human-agent teamwork in practice. NASA Intelligent Systems Program Human-Centered Computing Program workshop, Pittsburgh, PA: Carnegie Mellon University, 4-6 March.

55. Bradshaw, Jeffrey M. (2003). Making agents acceptable to people. Invited opening keynote speech, Third International Central and Eastern European Conference on Multi-Agent Systems (CEEMAS 2003), Prague, Czech Republic, June 16.

56. Bradshaw, J. M. (2003) A policy-based approach for collaboration in human-agent teams: Issues and applications. Invited keynote speech for the IAT 2003 workshop on Collaboration Agents: Autonomous Agents for Collaborative Environments (COLA '03). Halifax, Nova Scotia, 13 October.

57. Bradshaw, Jeffrey M. (2003). Living with agents: From human-agent teamwork to cognitive prostheses. Inaugural lecture as honorary visiting researcher at the Centre for Intelligent Systems and their Applications and AIAI at the University of Edinburgh, Scotland, 4 September.

58. Bradshaw, Jeffrey M. (2003). Living with agents: From human-agent teamwork to cognitive prostheses. Invited lecture, Siemens AG Corporate Technology, Munich, Germany, 12 September.

59. Bradshaw, J.M. (2003) Living with agents: From human-agent teamwork to cognitive prostheses. Invited colloquium at University of Southern California Information Sciences Institute, Marina del Rey, CA, 3 December.

60. Bradshaw, J.M., Jung, H., & Kulkarni, S. (2003) Dimensions of adjustable autonomy. Presentation at the University of Rochester, Rochester, NY, 8 December.

61. Bradshaw, J. M. (2004) Dimensions of adjustable autonomy and mixed-initiative interaction. IHMC seminar, 20 January.

62. Bradshaw, J. M. (2004). Dimensions of adjustable autonomy and mixed-initiative interaction. Department of Computer Science, Brigham Young University, 13 February 2004.

63. Bradshaw, J. M. & Suri, N. (2004) Policy-based approaches to increasing the acceptability of intelligent systems. Invited seminar at the IBM T. J. Watson Research Laboratory, Hawthorne, NY, 18 February 2004.

64. Bradshaw, J. M. & Suri, N. (2004). Human-Agent Teamwork and Agile Computing. Presentation and Poster delivered at the ARLADA CTA meeting, Boulder, Colorado, 26 February.

65. Bradshaw, J. M. (2004). Bridging the gap between multi-agent, multi-robot, and multi-human teams. *Presentation at the AAAI Spring Symposium,* Stanford, CA: AAAI Press, March 22-24.

66. Bradshaw, J. M. (2004). Semantically-rich policy representation, reasoning, and enforcement. Invited keynote address. Second International Conference on Trust Management. Oxford, England, 29 March-1 April.

67. Bradshaw, J. M., Uszok, A. & Jeffers, R. (2004). Toward semantically-rich policy representation: Issues and applications. *Conference on the Human Impact and Application of Autonomic Computing Systems (CHIACS2).* Yorktown Heights, NY: IBM T.J. Watson Research Center, 21 April.

68. Bradshaw, J. M. (2004). Dimensions of adjustable autonomy and mixed-initiative interaction. Invited colloquium at SRI, International, Palo Alto, CA, June 8.

Tutorials

69. Bradshaw, J. M. (2002). Semantic interoperability for human-agent teamwork and augmented cognition. Tutorial at the *Symposium on Intelligent and Mobile Agents*. National Tsing-Hua University, Hsin Chu, Taiwan, 19-20 February.

70. Bradshaw, J. M. (2003) Software agent technologies. Invited tutorial sponsored by the Computer and Communication Research Center (CCRC) of National Tsing Hua University, Hsin-Chu, Taiwan, 17-19 February.

71. Boy, G. & Bradshaw, J. M. (2003). From direct manipulation to agent management. Tutorial presented at HCI International, Heraklion, Crete, Greece, 24 June 2003.

72. Boy, G. & Bradshaw, J. M. (2003). From direct manipulation to agent management. Tutorial presented at the European Cognitive Science Conference (EuroCogSci). Osnabrueck, Germany, 9 September.

73. Bradshaw, J.M. (2003) A glimpse at the future of agent technology. Invited tutorial at the 2003 IEEE/WIC International Conference on Intelligent Agent Technology (IAT 2003), Halifax, Nova Scotia, 13 October.

74. Boy, G. & Bradshaw, J. M. (2004). Interaction design of highly automated domain-specific systems. Tutorial presented at the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI 2004), Vienna, Austria, April 26.